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Li et al.

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(54) **HIGH PERFORMANCE WIRELESS RECEIVER WITH CLUSTER MULTIPATH INTERFERENCE SUPPRESSION CIRCUIT**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(22) Filed: **Jan. 6, 2006**

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Related U.S. Application Data

(63) Continuation of application No. 10/889,939, filed on Jul. 13, 2004, now Pat. No. 7,010,070.

(60) Provisional application No. 60/541,670, filed on Feb. 4, 2004, provisional application No. 60/487,148, filed on Jul. 14, 2003.

(51) **Int. Cl.**

H04B 1/10 (2006.01)

H04B 7/216 (2006.01)

(52) **U.S. Cl.** **375/349; 370/342**

(58) **Field of Classification Search** **375/229, 375/236, 316, 346, 348, 349, 350; 370/342, 370/345, 445; 455/63, 296, 506, 562.1**

See application file for complete search history.

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Primary Examiner—Emmanuel Bayard

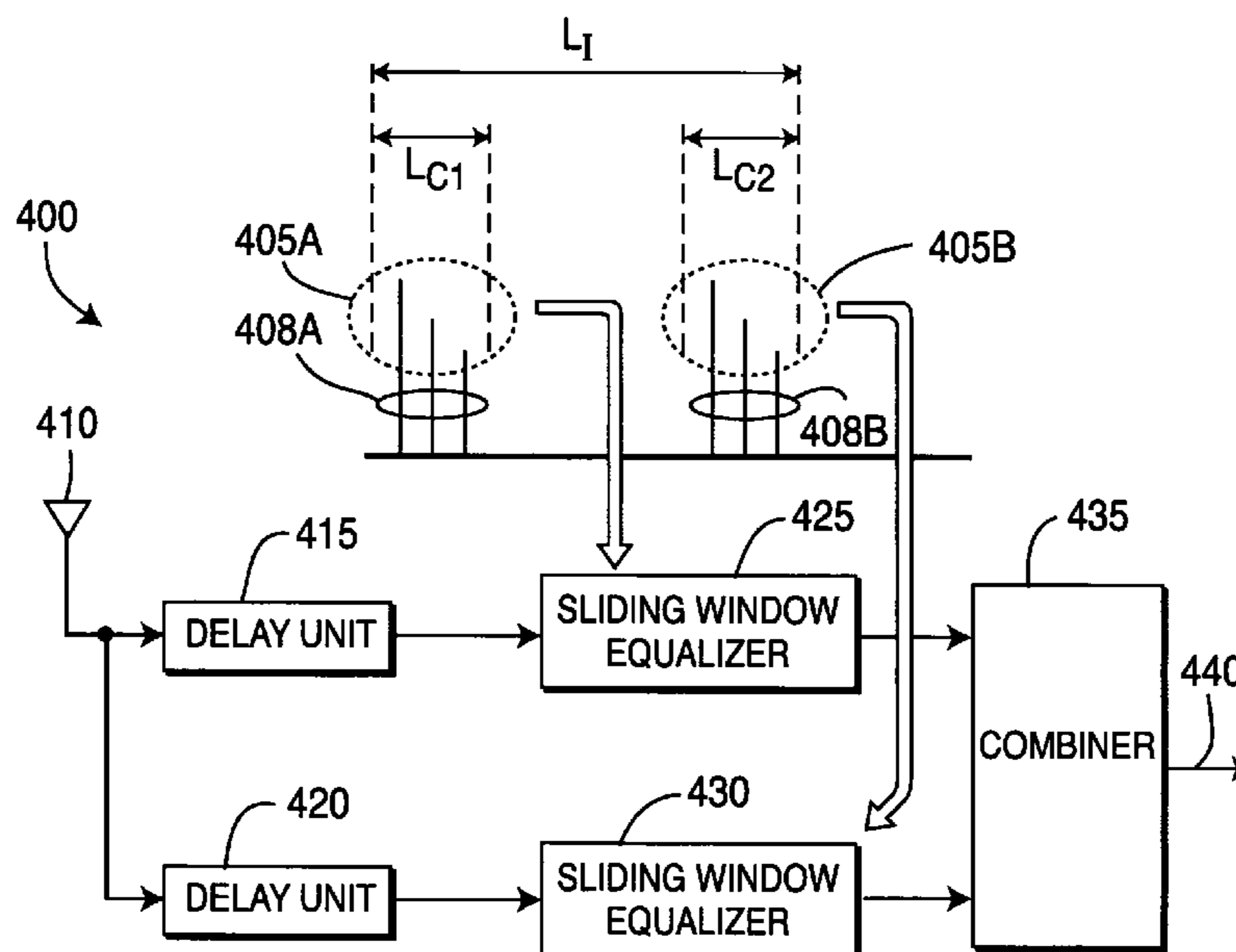
Assistant Examiner—Lawrence Williams

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(57) **ABSTRACT**

A receiver which suppresses inter-cluster multipath interference by processing an impulse channel response consisting of two multipath clusters, each cluster having groups of signals with multiple delays. In one embodiment, the receiver includes a single antenna and parallel-connected delay units used to align the groups of signals before being input into respective sliding window equalizers. The outputs of the equalizers are combined at chip level via a combiner which provides a single output. In another embodiment, a cluster multipath interference suppression (CMIS) circuit is incorporated into the receiver. The CMIS circuit includes a hard decision unit and a plurality of signal regeneration units to generate replicas of the multipath clusters. The replicas are subtracted from the respective outputs of the delay units and the results are input to the respective sliding window equalizers. In another embodiment, multiple antennas are used to receive and process the clusters.

18 Claims, 4 Drawing Sheets



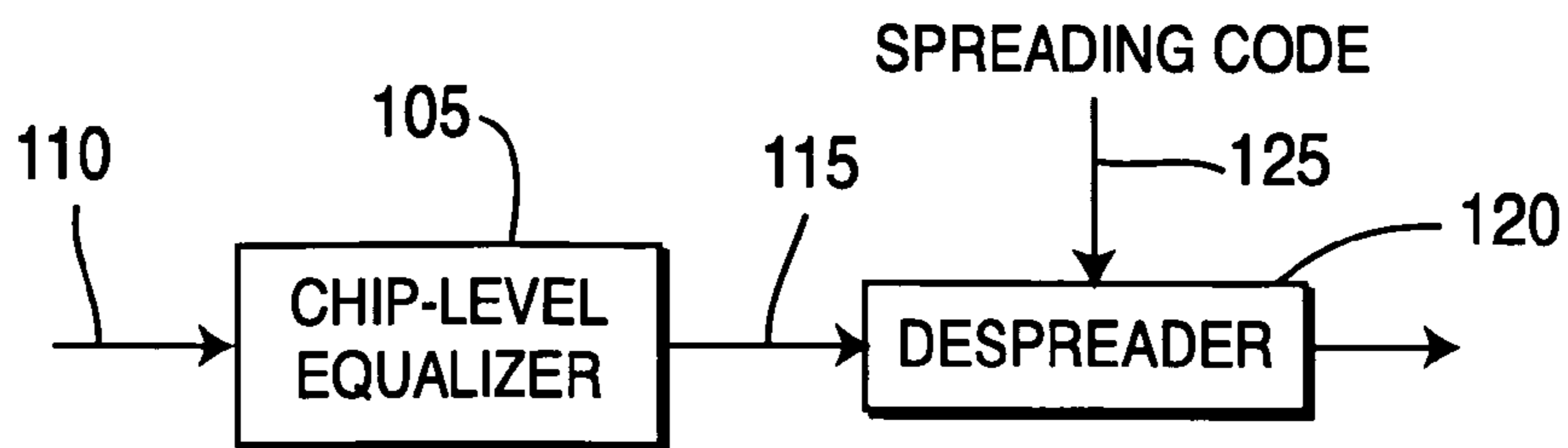


FIG. 1A
PRIOR ART

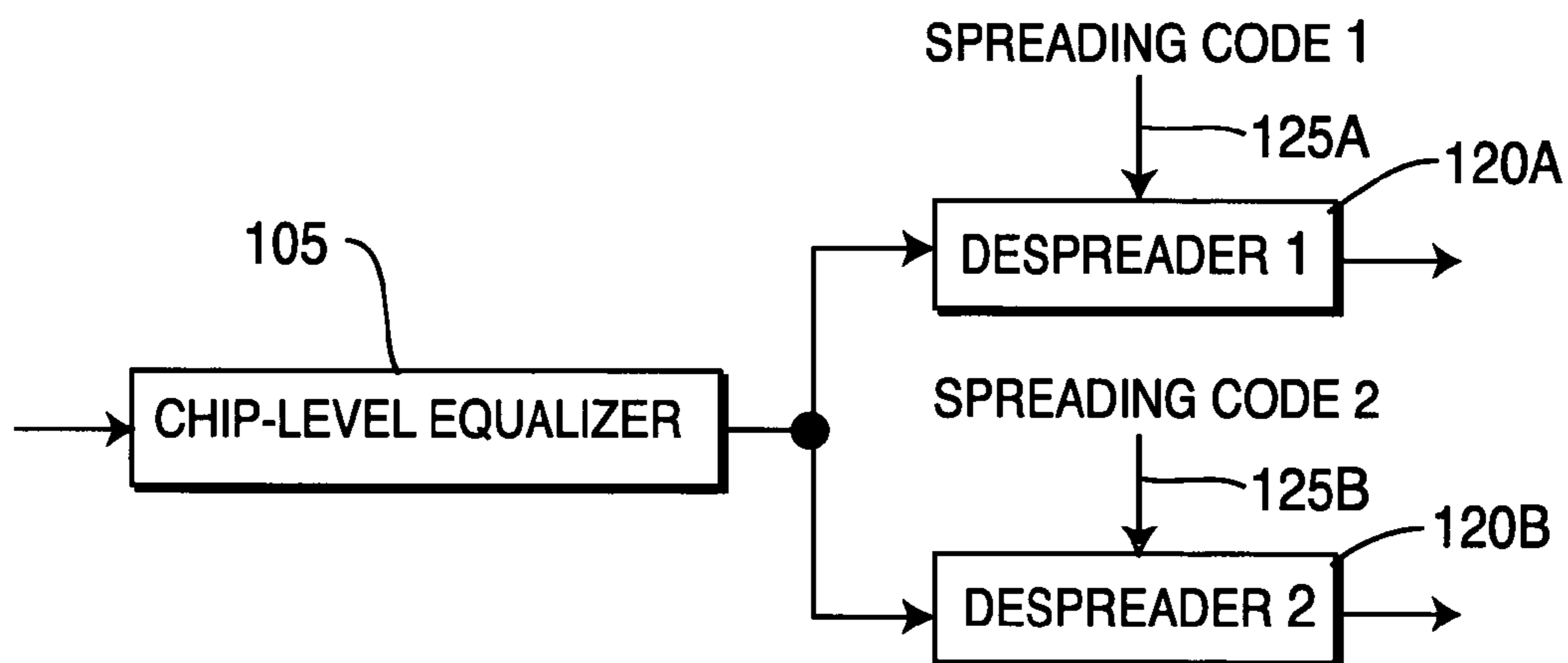


FIG. 1B
PRIOR ART

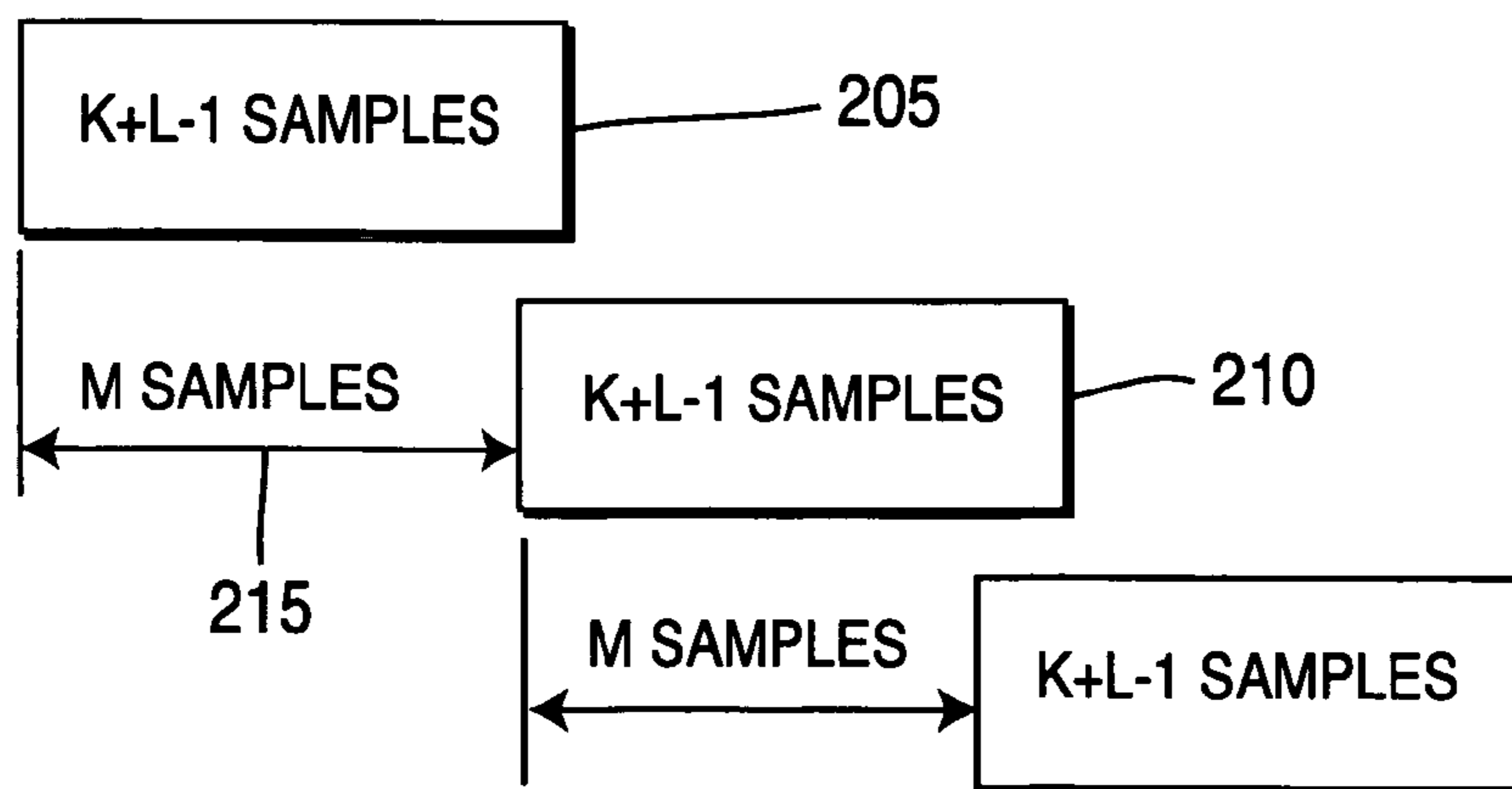


FIG. 2
PRIOR ART

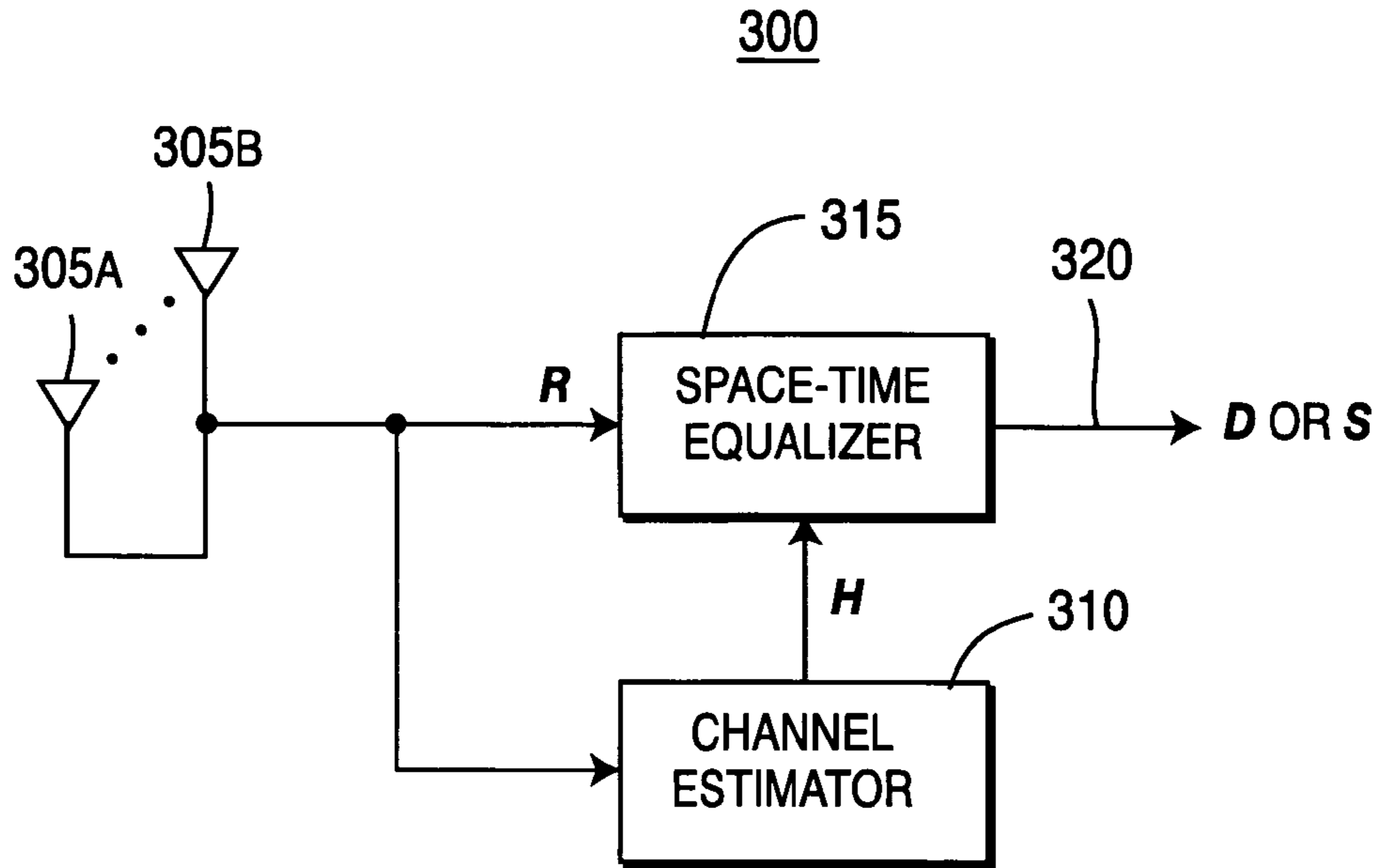


FIG. 3

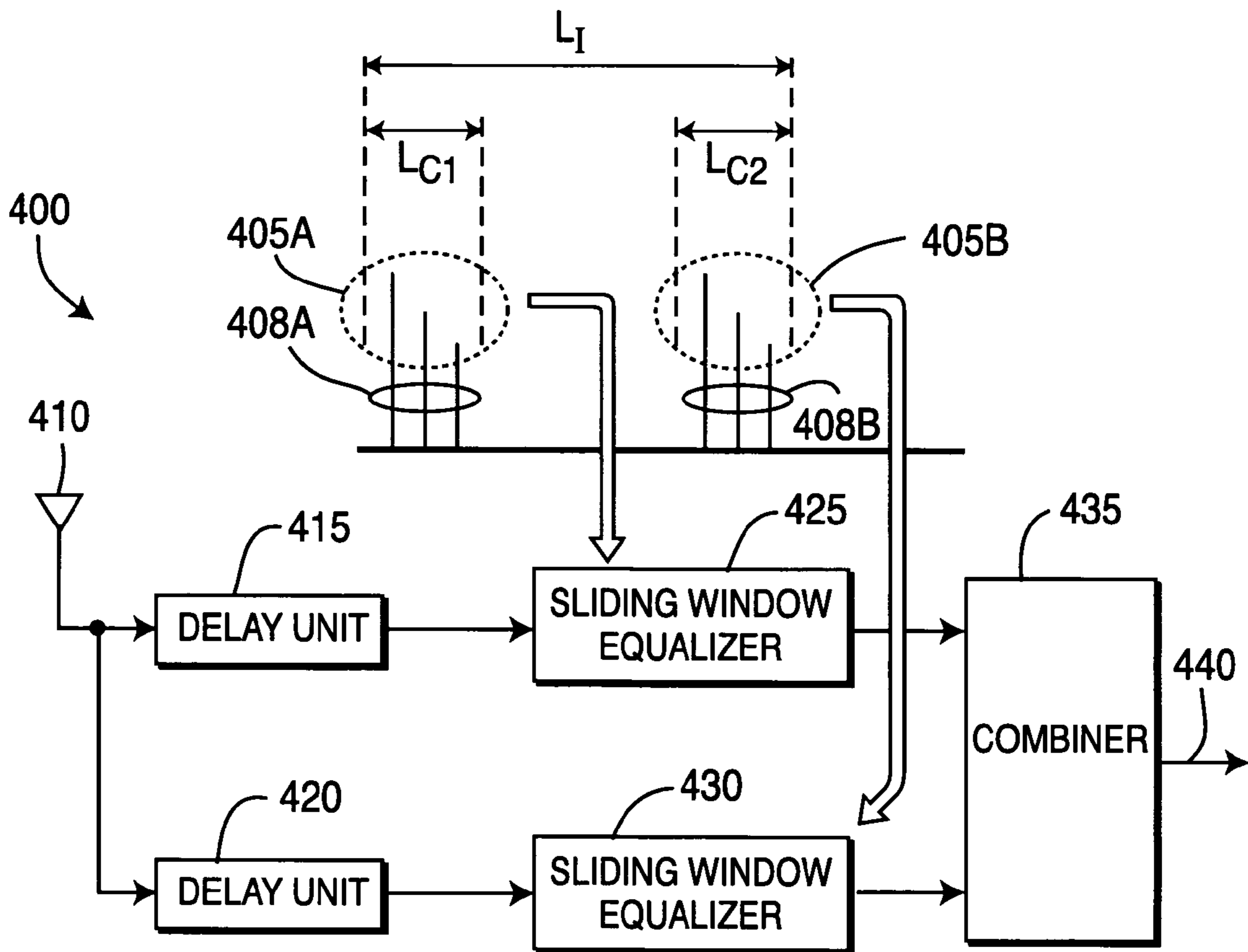


FIG. 4

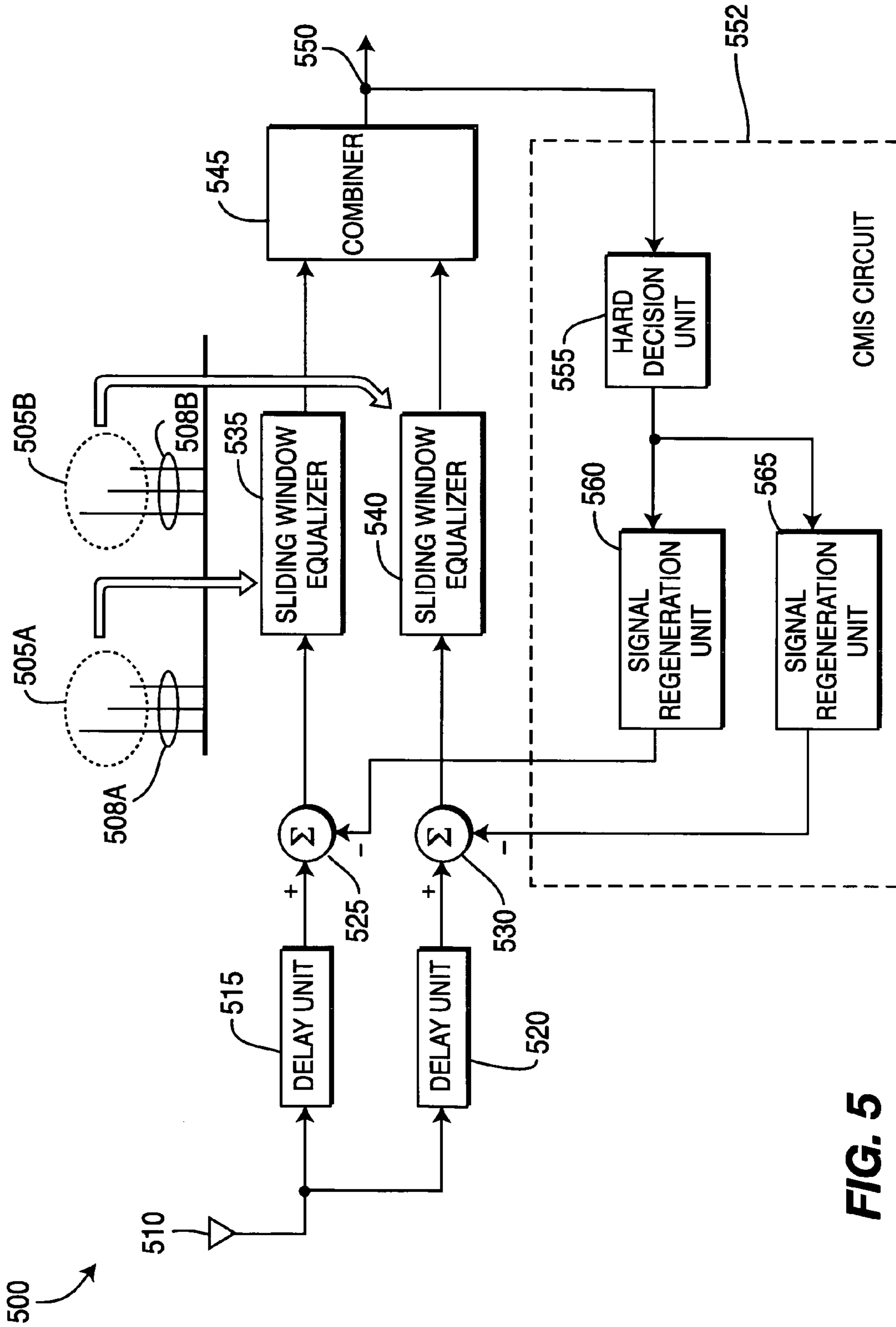


FIG. 5

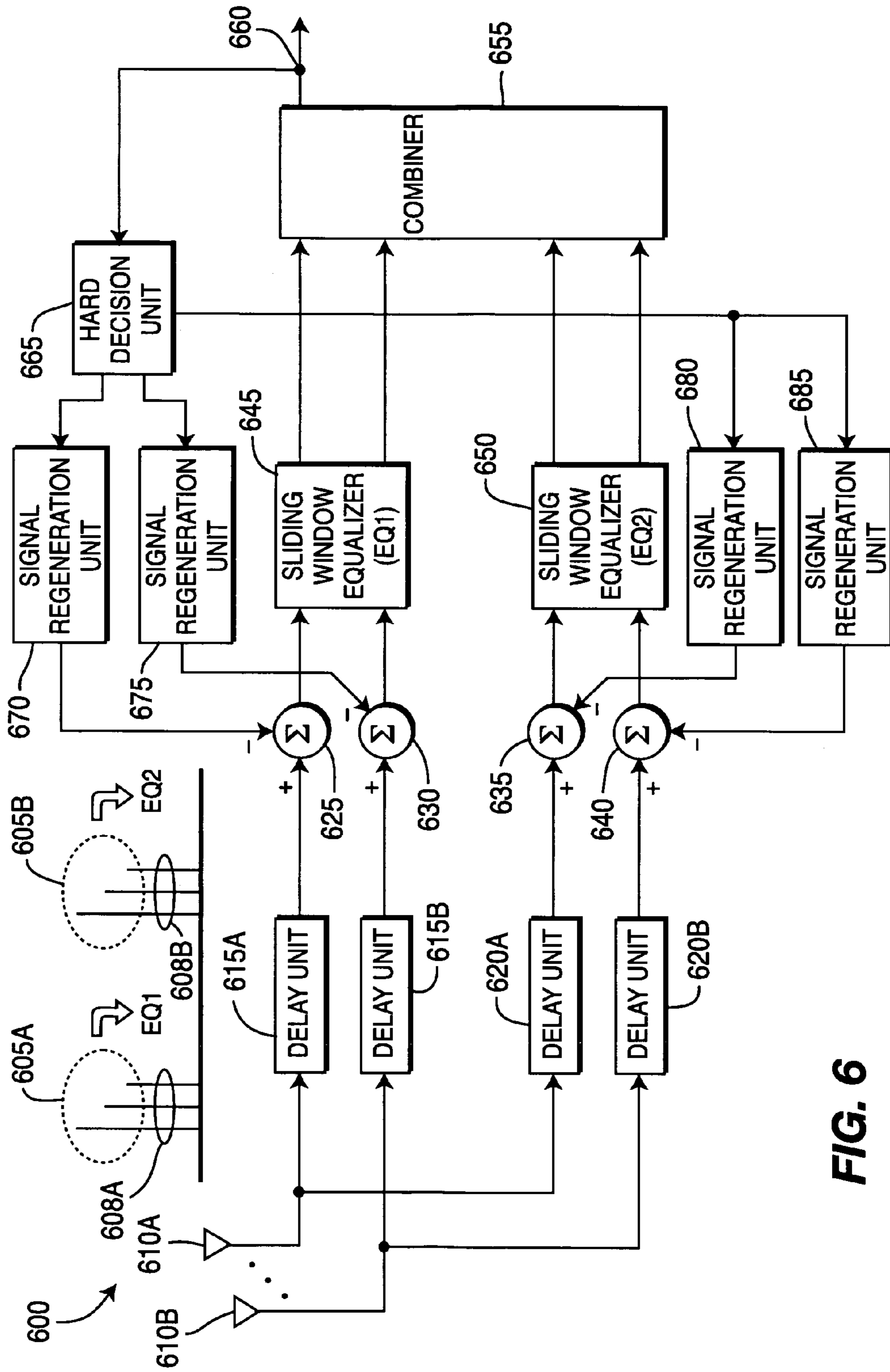


FIG. 6

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HIGH PERFORMANCE WIRELESS RECEIVER WITH CLUSTER MULTIPATH INTERFERENCE SUPPRESSION CIRCUIT

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 10/889,939 filed Jul. 13, 2004, now U.S. Pat. No. 7,010,070 which in turn claims priority from U.S. Provisional Application No. 60/487,148, filed Jul. 14, 2003, and U.S. Provisional Application No. 60/541,670, filed Feb. 4, 2004, which are incorporated by reference as if fully set forth.

FIELD OF THE INVENTION

The present invention relates to the field of wireless communications. More specifically, the present invention relates to a code division multiple access (CDMA) receiver for processing a wireless fading channel.

BACKGROUND

For wireless mobile applications using a CDMA air interface, a Rake receiver with a simple receiver structure is commonly used. The Rake receiver despreads each multipath component independently and treats other multipaths as noise. Therefore, the Rake receiver suffers performance loss, in particular when the spreading factor is small. In order to achieve better performance, other receiver designs have to be used.

As shown in FIG. 1A, a typical chip-level equalizer **105** may be used to equalize a receiver channel **110** and generate chip samples **115** with suppressed multipath interference for input into a despreader **120**, resulting in improved receiver performance. The despreader **120**, in FIG. 1A, uses a single spreading code **125**. Alternatively, as shown in FIG. 1B, multiple, such as two despreaders **120A**, **120B**, using respective spreading codes **125A**, **125B**, may be used in conjunction with the chip-level despreader **105**.

The chip-level equalizer **105** may have different implementations, such as using a minimum mean-square error (MMSE) criteria or a zero forcing (ZF) criteria. Since the MMSE equalizer typically performs better than the ZF equalizer, the MMSE equalizer is more commonly used, although ZF equalizers may be used.

It is desirable to provide a high performance wireless receiver, e.g., a CDMA receiver without the drawbacks of the known prior arrangements.

SUMMARY

The present invention is a receiver which suppresses inter-cluster multipath interference by processing an impulse channel response consisting of at least two multipath clusters, each cluster having groups of signals with multiple delays. In one embodiment, the receiver includes a single antenna and parallel-connected delay units used to align the groups of signals before being input into respective sliding window equalizers. The outputs of the equalizers are combined at chip level via a combiner which provides a single output. In another embodiment, a cluster multipath interference suppression (CMIS) circuit is incorporated into the receiver. The CMIS circuit includes a hard decision unit and a plurality of signal regeneration units to generate replicas of the multipath clusters. The replicas are subtracted from the

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respective outputs of the delay units and the results are input to the respective sliding window equalizers. In another embodiment, multiple antennas are used to receive and process the clusters.

The present invention is also a receiver including at least one antenna, a first sliding window equalizer, at least one processing circuit and a combiner. The antenna receives a transmitted wireless signal having a channel impulse response with at least one cluster. The processing circuit processes multipath components of the channel impulse response outside the window associated with the first sliding window equalizer. The combiner combines outputs of the first sliding window equalizer and the at least one processing circuit.

The first sliding window equalizer has a window length based on either a length of the at least one cluster or a predetermined cluster length. The at least one processing circuit may include a second sliding window equalizer having a window length based on either a length of a second cluster of the channel impulse response or a second predetermined cluster length. The at least one processing circuit may include a Rake.

BRIEF DESCRIPTION OF THE DRAWINGS

A more detailed understanding of the invention may be had from the following description, given by way of example and to be understood in conjunction with the accompanying drawings wherein:

FIG. 1A illustrates a prior art chip equalizer receiver with one code;

FIG. 1B illustrates a prior art chip equalizer receiver with two codes;

FIG. 2 illustrates prior art sliding window blocks for equalizer input data;

FIG. 3 is a block diagram of a channel estimation receiver system in accordance with one embodiment of the present invention;

FIG. 4 is a block diagram of a dual equalizer receiver in accordance with one embodiment of the present invention;

FIG. 5 is a block diagram of a dual equalizer receiver including a cluster multipath interference cancellation circuit in accordance with another embodiment of the present invention; and

FIG. 6 is a block diagram of a multi-antenna receiver including a cluster multipath interference cancellation circuit in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments will be described with reference to the drawing figures where like numerals represent like elements throughout.

Preferably, the present invention disclosed herein is incorporated into a wireless transmit/receive unit (WTRU) and/or a base station. However, it is envisioned that the just about any wireless communication scheme could benefit from the present invention.

Hereinafter, a WTRU includes but is not limited to a user equipment, mobile station, fixed or mobile subscriber unit, pager, or any other type of device capable of operating in a wireless environment. Furthermore, a base station includes, but is not limited to, a Node B, site controller, access point or other interfacing device in a wireless environment.

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where

$$\hat{S}_i^T = \begin{cases} (H_i^H H_i + \sigma_n^2 I)^{-1} H_i^H R & \text{MMSE equalizer} \\ (H_i^H H_i)^{-1} H_i^H R & \text{ZF equalizer} \end{cases}$$

\hat{S}_i^T ($i=1,2$) is the output of equalizer **425** or **430**, and H_i ($i=1,2$) is the channel response of cluster **405A** or **405B**.

To illustrate using FIG. **4**, the impulse response has a length of L_T . A first cluster **405A** has a length of L_{C1} and the second cluster **405B** has a length of L_{C2} . Instead of utilizing a sliding window equalizer configured to process a window of at least L_T in size, the sliding window equalizers can be configured to process a window of at least L_{C1} or L_{C2} in size. As illustrated in FIG. **4**, each cluster **405A**, **405B** has a length L_{C1} , L_{C2} , substantially shorter than L_T . In many impulse response profiles, the cluster length L_{C1} , L_{C2} is far less than the delay between the clusters, although some profiles may have a smaller delay between clusters. Due to the decreased window size, considerable complexity reduction can be achieved in the sliding window equalizers.

To support diversity between two cells, one equalizer **425**, **430**, may be assigned to each respective cell. If support of more cells is desired, or if simultaneous support of more cells and large delay spread signals is desired, more equalizer elements may be added, with, typically, at least one equalizer element per cell. However, the general combining principle would be the same as for the two-equalizer element case described above. The timing of the signal clusters transmitted by a base station may actually coincide in the code-phase (delay plane). However, since the clusters are typically implemented using different signature codes (such as scrambling codes), different equalizer elements may be applied.

The application of this receiver structure to multi-cell macro-diversity combining requires certain synchronization of the transmission of the (same) data from different sources (cells). This is a recognized requirement and is addressed in any cellular communication system that supports macro-diversity in the downlink. For example, UMTS FDD synchronizes transmission of data from different cells to within 292 chips. The residual delay can then be removed by an additional synchronization circuit at the receiver, which is essentially an extended delay buffer that is already present.

FIG. **5** is a block diagram of a receiver **500** which suppresses cluster multipath interference according to another embodiment of the present invention. The receiver **500** may reside within a WTRU and/or a base station. The receiver **500** processes an impulse channel response consisting of two multipath clusters **505A**, **505B**, each having groups of signals **508A**, **508B** with multiple delays. The receiver **500** includes a single antenna **510** connected to two parallel delay units **515**, **520** used to align the groups of signals **508A**, **508B**. The output of each of the delay units **515**, **520**, is connected to respective first inputs of summers **525**, **530**, which, in turn, connect to the inputs of respective sliding window equalizers **535**, **540**. The equalizers **535**, **540**, may be chip-level MMSE equalizers. The outputs of the sliding window equalizers **535**, **540**, are combined via a combiner **545** which provides a single output **550**. A CMIS circuit **552** is connected between the output **550** of the combiner **545** and respective second inputs of the summers **525**, **530**. The CMIS circuit includes a hard decision unit **555** having an input connected to the output **550** of the combiner

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545, and two signal regeneration units **560**, **565**, which are connected between an output of the hard decision unit **555** and the respective second inputs of the summers **525**, **530**. The signal regeneration units **560**, **565**, produce the contribution of each cluster to the receiver vector. The summer **525** subtracts the output of the signal regeneration unit **560** from the output of the delay unit **515** and outputs a first result to the input of the sliding window equalizer **535**. The summer **530** subtracts the output of the signal regeneration unit **565** from the output of the delay unit **520** and outputs a second result to the input of the sliding window equalizer **540**. Effectively, the summers **525**, **530**, remove the contribution of one or multiple clusters from the received vector, prior to processing by the sliding window equalizers **535**, **540**.

The output **550** of the combiner **545** may be defined by $\hat{S}^T = \hat{S}_1^T + \hat{S}_2^T$

where

$$\hat{S}_i^T = \begin{cases} (H_i^H H_i + \sigma_n^2 I)^{-1} H_i^H R_i & \text{MMSE equalizer} \\ (H_i^H H_i)^{-1} H_i^H R_i & \text{ZF equalizer} \end{cases}$$

\hat{S}_i^T ($i=1,2$) is the output of equalizer **535** or **540**, H_i ($i=1,2$) is the channel response of cluster **505A** or **505B**, and R_i ($i=1,2$) is a received signal with interference (from the other cluster) removed or subtracted.

As with FIG. **4**, within each cluster **505A**, **505B**, the spread between the multipath delays is relatively small. However, the delay in time domain between the two clusters **505A**, **505B**, is very large. In an alternate embodiment, one of the equalizers, such as the equalizer **540** may be replaced with a Rake.

The output **550** of the combiner **545** is used by the hard decision unit **555** to detect the transmitted signal by making a hard-decision. The signal regeneration unit **560** generates a replica of cluster **505B** and the signal regeneration unit **565** generates a replica of cluster **505A**. After generating the replicas of the two clusters **505B**, **505A**, they are subtracted from the aligned signals output from respective delay units **515**, **520**, via the summers **525**, **530**, respectively. If more than two clusters are processed, the contribution of multiple clusters is removed by each summer.

FIG. **6** is a block diagram of a multi-antenna receiver including a CMIC circuit in accordance with another embodiment of the present invention. The receiver **600** may reside within a WTRU and/or a base station. The receiver **600** processes an impulse channel response consisting of two multipath clusters **605A**, **605B**, each having groups of signals **608A**, **608B** with multiple delays. The receiver **600** includes at least two antennas **610A**, **610B**. Antenna **610A** is connected to two parallel delay units **615A**, **620A**, used to align the groups of signals **608A**, **608B**, received via the antenna **610A**. Antenna **610B** is connected to two parallel delay units **615B**, **620B**, used to align the groups of signals **608A**, **608B**, received via the antenna **610B**. The output of each of the delay units **615A**, **615B**, are connected to respective first inputs of summers **625**, **630**, which, in turn, connect to the inputs of a sliding window equalizer **645**. The output of each of the delay units **620A**, **620B**, are connected to respective first inputs of summers **635**, **640**, which, in turn, connect to the inputs of a sliding window equalizer **650**. The outputs of the sliding window equalizers **645**, **650**, are combined via a combiner **655** which provides a single

output 660. A CMIS circuit is connected between the output 660 of the combiner 655 and respective second inputs of the summers 625, 630, 635, 640. The CMIS circuit includes a hard decision unit 665 having an input connected to the output 660 of the combiner 655, and four signal regeneration units 670, 675, 680, 685, which are connected between an output of the hard decision unit 665 and the respective second inputs of the summers 625, 630, 635, 640.

The summer 625 subtracts the output of the signal regeneration unit 670 from the output of the delay unit 615A and outputs a first result to the input of the sliding window equalizer 645. The summer 630 subtracts the output of the signal regeneration unit 675 from the output of the delay unit 615B and outputs a second result to the input of the sliding window equalizer 645.

The summer 635 subtracts the output of the signal regeneration unit 680 from the output of the delay unit 620A and outputs a third result to the input of the sliding window equalizer 650. The summer 640 subtracts the output of the signal regeneration unit 685 from the output of the delay unit 620B and outputs a fourth result to the input of the sliding window equalizer 650. In an alternate embodiment, one or more of the sliding window equalizers may be replaced by a Rake.

The output 660 of the combiner 655 is used by the hard decision unit 665 to detect the transmitted signal by making a hard-decision. The signal regeneration units 670, 675, generate a replica of the cluster 605B and the signal regeneration units 680, 685, generate a replica of the cluster 605A. After generating the replicas of the two clusters 605B, 605A, they are subtracted from the aligned signals output from respective delay units 615A, 615B, 620A, 620B, via the summers 625, 630, 635, 640, respectively.

In a UMTS CDMA system, the present invention is applied to a large delay-spread channel and a single base station. However, the present invention also applies to multiple base stations. In the test case 2 of the UMTS wideband CDMA standard, the channel transmission profile has 3 paths with equal gain power and with the delay of 0, 960 ns and 20,000 ns. The first two paths are treated as the first cluster and a MMSE equalizer receiver is used to detect the signal. The last path is treated as a single path in the second cluster and a Rake receiver is used to detect that path.

While the present invention has been described in terms of the preferred embodiment, other variations which are within the scope of the invention as outlined in the claims below will be apparent to those skilled in the art.

What is claimed is:

1. A receiver comprising:

- (a) a plurality of antennas for receiving wireless signals, each wireless signal having a channel impulse response with at least one cluster;
- (b) a plurality of signal regeneration units, each signal regeneration unit being configured to generate a replica of the cluster associated with a respective one of the wireless signals received by the antennas;
- (c) a plurality of summers, each summer being configured to subtract the replica of the cluster generated by a respective signal regeneration unit from a respective signal received by a respective one of the antennas; and
- (d) a first sliding window equalizer having a window length based on either a length of the at least one cluster or a predetermined cluster length.

2. The receiver of claim 1 further comprising:

- (e) at least one circuit for processing multipath components of the channel impulse response outside the window associated with the first sliding window equalizer;
- (f) a combiner for combining outputs of the first sliding window equalizer and the at least one circuit; and
- (g) a hard decision unit coupled to an output of the combiner and to the signal regeneration units, wherein the at least one circuit comprises a second sliding window equalizer having a window length based on either a length of a second cluster of the channel impulse response or a second predetermined cluster length.

3. The receiver of claim 2 wherein the at least one circuit comprises a Rake.

4. The receiver of claim 1 wherein the window length of the first sliding window equalizer is a multiple of the length of the at least one cluster or the predetermined cluster length.

5. The receiver of claim 1 wherein the predetermined cluster length is a maximum expected cluster length.

6. The receiver of claim 1 wherein the predetermined cluster length is a multiple of a typical expected cluster length.

7. A wireless transmit/receive unit (WTRU) comprising:

- (a) a plurality of antennas for receiving wireless signals, each wireless signal having a channel impulse response with at least one cluster;
- (b) a plurality of signal regeneration units, each signal regeneration unit being configured to generate a replica of the cluster associated with a respective one of the wireless signals received by the antennas;
- (c) a plurality of summers, each summer being configured to subtract the replica of the cluster generated by a respective signal regeneration unit from a respective signal received by a respective one of the antennas; and
- (d) a first sliding window equalizer having a window length based on either a length of the at least one cluster or a predetermined cluster length.

8. The WTRU of claim 7 further comprising:

- (e) at least one circuit for processing multipath components of the channel impulse response outside the window associated with the first sliding window equalizer;
- (f) a combiner for combining outputs of the first sliding window equalizer and the at least one circuit; and
- (g) a hard decision unit coupled to an output of the combiner and to the signal regeneration units, wherein the at least one circuit comprises a second sliding window equalizer having a window length based on either a length of a second cluster of the channel impulse response or a second predetermined cluster length.

9. The WTRU of claim 8 wherein the at least one circuit comprises a Rake.

10. The WTRU of claim 7 wherein the window length of the first sliding window equalizer is a multiple of the length of the at least one cluster or the predetermined cluster length.

11. The WTRU of claim 7 wherein the predetermined cluster length is a maximum expected cluster length.

12. The WTRU of claim 7 wherein the predetermined cluster length is a multiple of a typical expected cluster length.

13. An integrated circuit (IC) embedded in a receiver having a plurality of antennas for receiving wireless signals,

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each wireless signal having a channel impulse response with at least one cluster, the IC comprising:

- (a) a plurality of signal regeneration units, each signal regeneration unit being configured to generate a replica of the cluster associated with a respective one of the wireless signals received by the antennas;
- (b) a plurality of summers, each summer being configured to subtract the replica of the cluster generated by a respective signal regeneration unit from a respective signal received by a respective one of the antennas;
- (c) a first sliding window equalizer having a window length based on either a length of the at least one cluster or a predetermined cluster length.

14. The IC of claim **13** further comprising:

- (d) at least one circuit for processing multipath components of the channel impulse response outside the window associated with the first sliding window equalizer;
- (e) a combiner for combining outputs of the first sliding window equalizer and the at least one circuit; and

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- (f) a hard decision unit coupled to an output of the combiner and to the signal regeneration units, wherein the at least one circuit comprises a second sliding window equalizer having a window length based on either a length of a second cluster of the channel impulse response or a second predetermined cluster length.

15. The IC of claim **14** wherein the at least one circuit comprises a Rake.

16. The IC of claim **13** wherein the window length of the first sliding window equalizer is a multiple of the length of the at least one cluster or the predetermined cluster length.

17. The IC of claim **13** wherein the predetermined cluster length is a maximum expected cluster length.

18. The IC of claim **13** wherein the predetermined cluster length is a multiple of a typical expected cluster length.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 7,127,014 B2
APPLICATION NO. : 11/327738
DATED : October 24, 2006
INVENTOR(S) : Li et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 1, line 41, after the word "chip-level", delete "despreader" and insert therefor --equalizer--.

At column 2, line 59, after the word "that", delete "the".

At column 3, Equation 1, line 28, column 2, delete " h_1 " and insert therefor h_L .

At column 3, Equation 1, lines 25, 26, 28, column 3, delete "." and insert therefor \cdot .

At column 3, lines 46 & 47, after the word "transpose", delete "Hermetian" and insert therefor --Hermitian--.

At column 6, line 28, after the words "505B, and", delete " R_1 " and insert therefor R_i .

At column 7, line 42, before "MMSE", delete "a" and insert therefor --an--.

Signed and Sealed this

Seventh Day of August, 2007



JON W. DUDAS

Director of the United States Patent and Trademark Office